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Human factors and autonomous ship operation : a comparative analysis of the maritime and aviation industries

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HUMAN FACTORS AND AUTONOMOUS SHIP OPERATIONS:

A Comparative Analysis of the Maritime and Aviation Industries.

by

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A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of

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Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views and are not necessarily endorsed by the University.

(Signature):

(Date): 22 September 2020

Supervised by: Professor Michael Ekow Manuel

Supervisor's affiliation: World Maritime University

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Abstract

Title of Dissertation: **Human factors and autonomous ship operations: A comparative analysis of the maritime and aviation industries.**

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It is perceived that Maritime Autonomous Surface Ships (MASS) will be the next big thing in the maritime industry and autonomous technology would be embraced sooner than later. Hence, it is prudent to consider measures that make their operations safe. This research explores the effect of human factors on autonomous ship operations and carries out a comparative analysis with the aviation industry regarding its approach towards adopting autonomous systems especially in regard to human factors.

This research was conducted using principles of qualitative research, by a Systematic Literature Review (SLR) technique followed by research synthesis conducted using a Qualitative Interpretive Meta Synthesis (QIMS). Data analysis was aided by the use of MAXQDA which is a Computer Assisted Qualitative Data Analysis Software (CAQDAS).

Human factors such as situational awareness, data overload and mental workload, out of the loop syndrome and skill degradation, automation induced errors, training and knowledge, and stress and fatigue, were studied in depth. Comparative analysis with aviation industry indicated that some of the human factors had similar impact upon both the industries, while other factors were seen as impacting both industries to varying degrees. This was primarily due to differences in operational requirements of the respective industries. However, this study identified 'automation induced error' human factor as an emergent factor for autonomous ship operations. Further, this research clearly identifies and recommends the most suitable measures for controlling human factors affecting autonomous ship operations.

KEYWORDS: Maritime, autonomous ships, human factors, human element, systematic literature review, aviation, remotely piloted aircraft, situational awareness, automation, autonomous

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List of Abbreviations

ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
BCI	Brain Computer Interface
BMI	Brain Machine Interface
C2	Control and Communication
CAQDAS	Computer Assisted Qualitative Data Analysis Software
CCD	Crew Centred Design
COC	Certificate of Competency
COP	Certificate of Proficiency
D&A	Detect and Avoid System
EICAS	Engine Information and Crew Alerting System
ECAM	Electronic Centralised Aircraft Monitor
GPS	Global Positioning System
HCD	Human Centric Designs
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation
IMO	International Maritime Organisation
ISO	International Organisation for Standardisation
MASS	Maritime Autonomous Surface Ships
MCA	Maritime Coastguard Agency
MCAS	Manoeuvring Characteristic Augmentation System

MET	Maritime Education and Training
MSC	Maritime Safety Committee
MTRB	Maritime Transportation Research Board
P&I	Protection and Indemnity
QIMS	Qualitative Interpretive Meta Synthesis
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft Systems
RPS	Remote Pilot Station
RSE	Regulatory Scoping Exercise
SA	Situational Awareness
SARP	Standard and Recommended Practices
SCC	Shore Control Centre
SLR	Systematic Literature Review
STCW	Standards of Training Certification and Watchkeeping
UAS	Unmanned Aircraft System
UK	United Kingdom
USA	United States of America
USCG	United States Coast Guard
WMU	World Maritime University

1 Introduction

1.1 Background

Automation, machine learning and artificial intelligence are already transforming various sectors of the global society. In fact, such technologies have made our lives seamless without our knowing how much we depend upon them. Technical feasibility and economic advantage due to improved efficiency and reduced operational and labour costs are the driving forces for the change towards a more technology-dependent society. So far, the aviation and automotive industries have shown more interest in autonomous systems and autonomous technology in these industries is maturing and evolving with time. The maritime industry has been exploring the idea of autonomous ships since 1980's. However, it has not made much progress in this regard so far (Fjelldal, 2018), although ships with varying levels of autonomy are being used in the field of ocean research and military applications (Ahvenjärvi, 2017). The merchant shipping industry is still far from adopting autonomous technology, despite the rapid pace of technological advancements. It is perceived that the use of ships with increasingly high levels of autonomy will be the next big thing in the shipping industry and this would gradually move the maritime industry towards adoption and integration of fully autonomous ships into the maritime transport system. Autonomous ship technology would utilise and exploit technologies such as sensors, robotics, big data, internet of things, artificial intelligence, machine learning, etc. These technological advancements impose numerous challenges, and it is of utmost importance for the maritime industry, that it takes early steps to ensure a safe and efficient transition towards autonomous ships (Lloyd's Register Group Limited et al., 2015).

The International Civil Aviation Organisation (ICAO) has developed and adopted a manual for Remotely Piloted Aircraft Systems (RPAS), which provides operational and technical guidance on issues related to remote operation of aircrafts. This is to ensure that the RPAS operations are conducted in a safe, harmonised, and seamless manner, and that in terms of safety they are comparable to manned aircrafts. The RPAS manual is seen as the aviation industry's initial move towards adoption and integration of remote aircraft operations and it is expected that these guidelines will mature and evolve over a period of time, and take the industry safely towards adoption of fully autonomous aircrafts (ICAO, 2015). Further, the adoption of the RPAS manual not only indicates that the aviation industry is a step ahead of the maritime industry in its move towards adoption of autonomous technology, but also indicates the aviation industry's approach i.e. to first operationalise and integrate remotely piloted aircrafts, prior to moving towards adoption of fully autonomous aircrafts. This approach of the aviation industry is similar to the approach adopted by the maritime industry, where initial levels of autonomous ships are in fact remotely operated ships.

The fact is that our world has been constantly changing and now even more rapidly. It is perceived that in future, unmanned and remote operations of all the modes of transportation would be a common feature of our lives, as they offer greater flexibility and operational efficiency. In the near future, the maritime industry would also have autonomous ships with varying levels of autonomy. However, autonomous ships or remotely operated ships do not mean that humans would be replaced by machines in all areas of ship operation. Autonomous ships would need to be remotely monitored or controlled depending upon their autonomy level and this would require new kinds of roles, tools, tasks, and environments to capitalise upon the new opportunity (Rolls-Royce, 2016).

1.2 Present status regarding autonomous ships

The Maritime Safety Committee (MSC) of the International Maritime Organisation (IMO) commenced a Regulatory Scoping Exercise (RSE) in 2018, with the aim of determining how existing IMO instruments apply to autonomous ships with varying levels of autonomy. The RSE is expected to be completed in the year 2020. Further, IMO has defined four levels or degrees of autonomy on ships (IMO, 2020) as follows:

Degree one: The ship has automated processes and is provided with decision support system. Seafarers are present on board to operate and control onboard systems and functions. Some operations may be automated and at times may also be unsupervised, but there would be seafarers on board to take control if required. Most of the newer vessels, presently operating would fall in this category.

Degree two: Remotely controlled ship with seafarers on board. The ship is operated and controlled from another location and would have limited number of seafarers on board to take control and operate the shipboard systems and functions if required.

Degree three: Remotely controlled ship without any seafarers on board. The ship is controlled and operated from another location.

Degree four: Fully autonomous ship. The autonomous system of the ship makes its own decisions and determines actions by itself, with minimal human interface.

The RSE being conducted is seen as the first step taken by the maritime industry towards Maritime Autonomous Surface Ships (MASS). The RSE is a comprehensive exercise that will look into a whole range of issues expected to arise with the implementation of autonomous shipping operations. These include issues related to the human element, safety, security, liability and compensation in case of damage, emergency response and the interface with ports and pilots, among others (IMO, 2020).

1.3 Problem statement

To ensure sustainability of autonomous shipping, it is important to ensure that their operation is carried out in a safe and efficient manner. One of the key focus areas of this research is to study the potential effect of human factors on autonomous ship operations.

The main driving force for adoption of autonomous technology is the perception that it would lead to reduction in accidents which are caused by human error. Studies indicate that about 80% of maritime accidents are caused by the human error (Ramos et al., 2018). Commercial shipping operations are influenced by different factors, such as the human factor, ship factors, environment factors, management factors and external factors (ports and the other third-party interfaces). It is expected that, all these factors, to varying degrees, would also affect autonomous ship operations. Hence, it is important to understand how these factors would interact amongst each other to pose risks, either together or in isolation for safe and reliable autonomous ship operations. While it is important to consider all the stated factors, this work is focused on the human factor as probably the most important factor to consider in socio-technical systems.

Irrespective of the different levels of autonomy of MASS, it can be stated that, shore operators would be remotely controlling operations of level two and level three autonomous ships and would be supervising level four autonomous ships. The shift from onboard operations of contemporary conventional ships to shore-based operations of autonomous ships, would bring in new aspects of human factors affecting ship operations. The effect, therefore, of such human factors on autonomous ship operations needs to be carefully examined and understood, to ensure that appropriate and effective actions are taken to prevent the occurrence of human error (Ramos et al., 2018).

1.4 Research aims and objectives

Although there is substantial literature available on technical aspects of automation, there is not enough literature available regarding human capabilities in working with automation systems (Janssen et al., 2019), even though these considerations play a key role when designing human-machine interactions and working environment (Dybvik et al., 2020). Similarly, there is apparently no research, where comparative analyses of the effect of human factors on autonomous systems in the aviation industry is used to draw out lessons for the maritime industry regarding the adoption of autonomous technology.

The objective of this research, therefore, is to explore the effect of human factors on autonomous ship operations using a systematic literature review as a research method based on which a comparative analysis of the aviation industry vis-à-vis the maritime industry is undertaken. This is done with a view to draw out lessons for the maritime industry through the critical review of measures taken by the aviation industry to overcome challenges regarding human factors in the adoption of autonomous technology.

1.5 Research Questions

This research aims to answer the following questions

Question 1: What is the role of the human factors in a risk management paradigm in autonomous ship operations?

Question 2: What steps are taken by the aviation industry in overcoming challenges posed by human factors in the adoption of autonomous technology?

Question 3: What lessons can be drawn from autonomous operations in the aviation industry to optimise human factors in maritime autonomous surface ship (MASS) operations?

1.6 Research Methodology

This research primarily took a qualitative methodological approach. The specific method used was a Systematic Literature Review (SLR) followed by research synthesis using a Qualitative Interpretive Meta Synthesis (QIMS) approach. Data was analysed with the aid of MAXQDA, a Computer Assisted Qualitative Data Analysis Software (CAQDAS). To remove researcher subjectivity and bias, the initial screening of literature for inclusion in the research was done by a 'Scaled-back Delphi method', where a panel of six experts from the maritime industry with experience in different maritime aspects and from different global jurisdictions screened the literature that was obtained after initial search.

1.7 Limitation of the research

The research is limited in scope to the identification of human factors which would affect the operators of the autonomous ships. Other important factors mentioned earlier in the text, including ship factors, environment factors, management factors and external third-party factors, are not addressed in this work.

Furthermore, this research focuses on human factors affecting remotely operated autonomous ships i.e. IMO autonomy levels two and three ships. The work was limited to these two levels because the maritime industry's move towards the adoption of fully autonomous ships is expected to be "evolutionary rather than revolutionary" (World Maritime University, 2017) i.e. incremental rather than radical. The selected levels are the most pragmatic to consider for the purposes of the near future.

Another limitation of the work relates to the number of published work in the domain. Since autonomous shipping is still at a nascent stage of development, the human factors ascertained are necessarily drawn from only the existing literature available. Additionally, this research only pertains to human factors and its effect upon the autonomous ship operations and does not look at any other aspects of autonomous ship operations.

1.8 Structure of the dissertation

This chapter address the outline of this research, which includes a brief introduction to autonomous technology and the measures being taken by the maritime industry towards adoption of same. Thereafter, it illustrates the rationale behind the research questions and the research methodology adopted. Chapter 2 is the preliminary literature review and the systematic literature review, and begins with a discussion on human element and human factors. The research methodology used is elaborated in Chapter 3. Chapter 4 presents the research results i.e. human factors which would affect autonomous ship operations, and also human factors which are affecting remotely piloted aircrafts, it also includes guidelines adopted by the aviation industry to control the effect of human factors. Subsequently, Chapter 5 discusses the research results, to draw out the learning, by way of recommendations for the maritime industry in their quest for adoption of autonomous technology and then finally conclusion to end the chapter.

2 Literature review

This section starts with a discussion to gain understanding of human factors and human element and the link between human error and human factors as evidenced in the literature. Thereafter there are separate sections, analysing human factors and their impact upon autonomous systems in the maritime industry and in the aviation industry. The section's initial part reflects the findings of the preliminary literature review which formed the basis of this study, and the latter part reflects the systemic literature review which was conducted to find answers to the research questions of this study.

2.1 Human element and human factors

The terms 'human element' and 'human factors' lack a clear distinction between them and some of their aspects are seen to overlap with each other. Further, in many industries, these terms are seen to be used interchangeably. IMO describes the human element as:

> A complex multi-dimensional issue that affects maritime safety, security, and marine environmental protection. It involves the entire spectrum of human activities performed by ship's crews, shore based management, regulatory bodies, recognised organisations, shipyards, legislators, and other relevant parties, all of whom need to co-operate to address human element issues effectively (IMO, 1997).

The above shows that the focus of IMO, in regards to human element issues is on safety, risk mitigation, and environmental protection. However, there is no agreed taxonomy or standard definition of human element issues and it is found to vary across the industries. For example, for the Maritime Coastguard Agency (MCA), United Kingdom (UK), human element issues pertain to human resource management, which includes recruitment, selection, retention, health, and well-being of seafarers (Barnett & Pekcan, 2017).

Looking at human factors, it is defined by the International Ergonomics Association as follows:

> Human factors or ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. The terms ergonomics and human factors are often used interchangeably (IEA, n.d.).

The term ‘human factors’ was widely used in USA, while the term ‘ergonomics’ was more pervasive in Europe (Rumawas, 2015). The UK government HSE department, defines ‘human factors’ as environmental, organisational and job factors, and human and individual characteristics which influence individual’s behaviour at work such that it affects health and safety. In other words, human factors has three aspects to it, i.e. the job, the individual and the organisation, and the effect they have on people’s health and safety-related behaviour (U.K HSE, 1999).

It can be seen from above that, there are no clear distinct boundaries between definitions of ‘human element’ and ‘human factors’. The term ‘human element’ does appear to cover a much broader context and “human factors” may be considered as a subset of this broader notion of the human element. Since this research focuses on human-related issues vis-à-vis operational equipment in the context of autonomous technology, it is more aligned with the definitions of human factors. Accordingly, for this research the term ‘human factors’ is used, even when it deals with subjects which may be more closely aligned with a definition of human element.

2.2 Human error and human factors

Human beings have the tendency to make mistakes, and/or at times to deviate from rules to save time or otherwise, and when such mistakes or omissions have the potential to affect others and/or organisations which they are part of, these mistakes need to be examined carefully to ensure necessary steps are ascertained and taken for preventing recurrence of these mistakes. Safety Research Institute states that, human error may happen when the work requirement of a system or the work environment therein is not consistent with human characteristics. Human characteristics are affected by various factors such as environmental conditions, social setting, rules and regulations, human interface with machines, etc. In an environment where people interact with devices or systems, human characteristics affect overall functioning of the system in different ways. These human characteristics and work environment factors are collectively known as human factors (West Japan Railway Company, n.d.).

In any work environment, it is important to understand the role of humans in functioning of that system and know the characteristics of humans (human factors) and then develop a system which is aligned and consistent with human factors in order to reduce the chances of occurrence of human error.

2.3 Human factors affecting the maritime industry

2.3.1 Introduction

In the early 1970s, the Maritime Transportation Research Board (MTRB), of United States of America (USA) commenced research work to investigate causal factors of numerous accidents which happened at sea, with an aim to provide recommendations to prevent their re-occurrence. The research showed human factors as one of the major contributory causes for most of the accidents. In 1993, the United States Coast Guard (USCG) reported that 80% of maritime accidents were caused by the human error and in 1994 IMO reported that 75% accidents were the result of human error. In the same year, a reputed Protection and Indemnity (P&I) club reported that 63% of the reported accidents between 1987 and 1993 were caused by human error (Grech et al., 2019).

While human error is thought of as arising from mistakes or inattention, they indicate the presence of deeper and complicated issues within the system. Human error is caused by individual and organisation factors, job factors, technology factors and environments factors, i.e. when these factors are in some ways incompatible with human performance. These factors are collectively known as human factors and these are the main causes behind the occurrence of human error. Human factors is the domain where human capabilities and limitations are understood, and this information is applied to the design of equipment, design of the work environment, and the formulation of procedures and policies to ensure that these are and remain compatible with the human abilities. This is also known as human-centric approach and has numerous other benefits besides causing a reduction in human error and thereby reduction in accidents (Rothblum, 2000). In recent years, there has been significant growth of the human-centric approach in the maritime sector.

2.3.2 Autonomy and automation in the maritime industry

To understand the effect of human factors on autonomous ship operations, we first need to clearly understand the characteristics of autonomy and automation and the level of human interface required in each of these systems. The terms autonomy and automation are often interchanged and they do not have a clear distinction between them. However, they complement each other and clearly define the human interface required by each to achieve their outcome or goals. An automation system generally has a pre-programmed link between sensor input and the system output, and because of this pre-programmed functionality it has a limited capacity in handling unforeseen situations. On the other hand, an autonomous system generally requires a set of automated functions along with artificial intelligence for decision-making capacity, which is embedded with machine learning abilities. Enhanced computerised sensing, monitoring, and control of physical process and systems have led to an increased level of autonomy. Autonomy is of different levels depending upon how advanced the autonomous system is i.e. the level of human interface that is required for it to function (Fjellheim, 2020).

2.3.3 Human factors affecting the autonomous ship operations

Despite the different opinions about the (de)merits of autonomous ships, efforts to see them become a part of maritime industry are growing. It is prudent therefore, to consider measures that make their operations safe. As indicated previously, less-than-optimum consideration of human factors leads to human error which in turn leads to accidents. Hence, to ensure the growth of autonomous ships, we need to understand and mitigate the adverse effects of technological systems on humans. Automation, if designed properly, could assist in reducing the workload of humans. However, studies indicate that under certain circumstances especially during disruptions, higher levels of automation may in fact lead to increased workload (Balfe et al., 2015). Furthermore, autonomous systems may cause errors of omission and/or commission. Errors of omission occur when an operator fails to detect a deviation because the system is unable to detect it while errors of commission occur where an operator responds incorrectly to a deviation detected by the system, as information is not crosschecked by the operator prior taking an action (Porathe, 2014). It is argued that this problem is not a result of the automation per se but rather due to its design. Another issue noted is the diminished feedback in the automated systems, which not only increases the operator's secondary task involvement but also leads to inappropriate reliance on the automated systems (Meyer & Beiker, 2016).

Autonomous ships are expected to address existing human factors like fatigue, limited human attention span, normality bias etc. thereby increasing the safety in the maritime industry. However, this does not mean that existing human factors in the maritime industry would be eliminated. On the contrary autonomous ship operations would bring in new human factors while existing human factors may continue to be present but to a lesser extent. Autonomous ships (depending on level of autonomy) would depend on system elements/factors such as remote operators who would monitor the vessel remotely from Shore Control Centres (SCC), design of the equipment installed at SCC, design of the algorithms of the autonomous systems, environment created at the SCC, reliability of technology in use, training and competence level of the remote operator, etc. (Kristoffersen, 2020). These aspects of autonomous ship operations (some old, some new) would bring different kinds of human factors into play. Hence, there is a substantial need for a focused approach towards understanding human factors and their affect upon autonomous ship operations so as to ensure that appropriate mitigating measures are ascertained and integrated, for safe and sustainable operations of autonomous ships (Porathe et al., 2014).

While human factors have been substantially researched for conventional ships, research needs to be carried out regarding human factors and their effect on autonomous ship operations.

2.4 Human factors affecting the aviation industry

2.4.1 Autonomy and automation in the aviation industry

Continuous increase in air traffic has prompted transformation of the aviation industry. This transformation is underpinned by increasing reliability of new technologies such as autonomous systems and machine learning, intention to improve the capacity and profitability of airline services, and a promise to improve safety and environmental protection (Emanuilov, 2017). Unmanned Aircraft System (UAS) is a system where aircraft with varying levels of automation up to being fully autonomous, are operated without any pilot on board and the aircraft is remotely controlled and monitored. UAS has seen significant growth in commercial drones, especially in the field of remote sensing, agriculture, entertainment, the military, etc. and now the technology is maturing and is being adopted for use in the commercial aviation sector.

With present technology, aircrafts are able to land and cruise using automated onboard systems, with onboard pilots manually controlling the aircraft for just a few minutes on average. Automation of aircraft taxiing and take-off is not yet fully integrated, though Airbus has confirmed that it did automatic take-off of commercial aircraft in France, in Dec 2019. In fact, Airbus successfully achieved a total of eight automatic take-offs within a period of about four hours (Airbus, 2020). This was made possible by use of new image recognition technology which is installed on the aircraft, and which allows aircraft to navigate and detect obstacles during taxiing, take-off, approach and landing (Hardingham-Gill, 2020). Dubai is expected to launch a flying taxi service for passengers by 2025 and Singapore by 2030 (BBC, 2020). Boeing and Airbus are committed to having a fully autonomous commercial airplane by 2025 (Performance Software, 2019b). Autonomous system in aviation comprises mainly of three stages i.e. a first stage of arrangement of sensors to collect data, a second stage to collate the data gathered and feed it to artificial intelligence algorithms for determining a response and in the last stage the system responds without human involvement or with limited human involvement and continues to learn with time using machine learning abilities (Performance Software, 2019b).

Though the aviation industry is further ahead of the maritime industry in the adoption of autonomous systems, there are some who argue that replacing pilots with a computer would be taking away a significant safety resource (European Cockpit Association, 2020). It is a well-known fact that humans do introduce some failure scenarios. However, they also do eliminate numerous system failure scenarios and they are capable of adapting to unknown situations and taking prompt decisions accordingly. Autonomous systems are as good as their system design and what is fed in algorithms. This argument is also in line with the ‘safety II’ theory of Erik Hollnagel, where safety is not just minimizing bad outcomes but also maximizing good outcomes (Hollnagel, 2014). How much actually humans contribute towards good outcomes and if the autonomous systems would be able to fill in for the absence of humans, especially in a complex environment, is yet to be ascertained. It has been noted that this aspect needs to be well understood and factored in, prior to the adoption of a fully autonomous system in the commercial aviation sector (European Cockpit Association, 2020).

2.4.2 Human factors affecting remotely piloted aircrafts

All new technologies, including autonomous systems, come with their own risks and one of the most important aspect in regards to autonomous technology is, its reliance upon statistical processes to make their decisions. Furthermore, the system is exposed to other risks such as, initial teething problems, component malfunction, sensor blindness, etc. However, a substantial risk to autonomous systems comes from human factors, as humans play a critical role in autonomous operations, even though their role may vary depending on the degree of autonomy of the system. (Performance Software, 2019a). Statistics show that Remotely Piloted Aircraft (RPA) have experienced higher accident rates when compared to the conventionally piloted aircrafts (Hobbs, 2017). Investigations indicate that most of these accidents are the result of human challenges associated with piloting an RPA and due to Remote Pilot Stations (RPS) being designed with insufficient human factor considerations. It has been recognised by numerous aeronautical administrations including The National Aeronautics and Space Administration (NASA), that human factors need to be understood and guidelines incorporated to ensure safe and sustainable RPA operations. Over a period of time the aviation industry has developed guidelines for the safe operation of RPA, using data from simulations, accident and incident investigations, and also from the literature of human factors affecting Remotely Piloted Aircraft System (RPAS) (Hobbs & Lyall, 2016).

This research intends to conduct a comprehensive study of human factors affecting RPAS with an aim to draw out lessons for the autonomous ship operations.

3 Research Methodology

This research mainly pertains to human factors in autonomous shipping and involves the carrying out of a comparative analysis with the aviation industry regarding its approach towards the adoption of autonomous systems especially in regards to human factors. The objective of this research is to identify measures to be adopted by the maritime industry to overcome challenges, regarding human factors while adopting autonomous systems.

Autonomous ships have not yet been introduced to the commercial maritime sector in general and it may be said to be still in a research and development stage. Due to this, information regarding autonomous technology and its requirements for shipping is presently limited only to the organisations or companies which are involved in its development. Most seafarers and shipping companies have not yet been exposed to this new technology, hence they may not have adequate knowledge regarding same. Further, IMO has only recently taken its first step towards the adoption of autonomous ships by initiating the scoping exercise referred to earlier in this work, to identify measures which would be needed to ensure the seamless adoption and integration of autonomous ships in the maritime industry.

In view of the above, surveys and interviews were not considered as suitable methods for this research. The sample size with such approaches would have limited external validity. This research was therefore conducted using principles of qualitative research, by a Systematic Literature Review (SLR) technique followed by research synthesis conducted using a Qualitative Interpretive Meta Synthesis (QIMS) approach. Data analysis was aided by the use of MAXQDA which is a Computer Assisted Qualitative Data Analysis Software (CAQDAS).

Qualitative research is a research method where data is not in the form of numbers. It tends to be exploratory in nature seeking to explain the 'hows' and 'whys' of an occurrence of particular issues, phenomena or behaviour in particular or specific contexts. The results provide a deep understanding of how people perceive such issues, phenomena or behaviour and in consequence how they act within that specific context (Mcleod, 2019).

However, many researchers critique qualitative research methods, as they point out difficulties in synthesising studies from diverse research methodologies to a platform of common understanding and believe that the process discourages thoughtful evaluation and analysis. It is argued that qualitative research tends to be biased and subjective in nature and that two different readers analysing the same theme may come to different conclusions. This nature of qualitative research has triggered disagreement and debate within the academic community (Bearman & Dawson, 2013). On the other hand, quantitative research, because of systematisation of the process, is considered to remove the bias and subjectivity of the study and makes a worthy contribution in espousing the research methodology. However, it is critiqued that it gives little recognition to the variety of qualitative literature available. It follows the basic philosophy that all that is worth knowing is measurable and it ignores that this is not always the case (Suri & Clarke, 2009). Colliver (2008) showed that even quantitative research methodology is prone to bias and confounds (Colliver et al., 2008). It is acknowledged that qualitative research methods, because of their in-depth focus and analytical details within a specific context, do provide invaluable information which aids in increased understanding of existing themes or act as stepping stones for the formation of new themes (Suri & Clarke, 2009). The controversy and the debate regarding both qualitative and quantitative research methodologies is the result of a philosophical tension between the two methodologies which needs to be fully understood prior to selecting an appropriate research method (Bearman & Dawson, 2013).

3.1 Systematic Literature Review

SLR involves a process of systematically searching for literature and identifying, collecting, critically analysing, and integrating data from the collected literature to answer research questions. SLR aims to minimise subjectivity and bias by adopting a systematic search process to locate all published and unpublished work pertaining to the research questions, and the systematic synthesis and presentation of the findings of the review conducted (Siddaway et al., 2019). The aim of this research is to review the existing literature to ascertain the clear implications regarding policy and practice for upcoming autonomous ships in regards to human factors.

3.2 Stages of the systemic literature review

3.2.1 Scoping

Scoping is a stage in SLR where key issues were assimilated and then broken down into clear and specific research questions. Based upon the time frame available, the scope and breadth of the research questions were checked for appropriateness. Thereafter, literature pertaining to research questions is checked to ascertain the existing gaps, to determine the focus of the research, and to ensure that it remains contemporary (Siddaway et al., 2019). This research pertains to human factors regarding autonomous ship operations and a comparative analysis of steps taken by the aviation industry regarding human factors in adopting autonomous technology. This comparative analysis is done with a view to draw lessons for the maritime industry. While there has been some research done regarding human factors and autonomous ships, apparently no research has been done where maritime industry is able to draw lessons from the experience of aviation industry regarding adoption of autonomous technology with a focus on human factors. Hence, this argument establishes a strong rationale for conducting this research.

3.2.2 Planning

At this stage research questions were broken down into concepts to carry out an exhaustive search to ensure as many as possible relevant articles were found. The search carried out was balanced between sensitivity (finding all possible relevant articles) and specificity (ensuring that articles found are relevant). However, in order to ensure nothing was left out, at this stage the search was allowed to err on the side of sensitivity (Siddaway, 2014). Further, inclusion and exclusion criteria (Table 1) were established and uniformly applied. Scope of the search was limited to last 15 years as discussions pertaining to autonomous ships increased during this period, and moreover fast pace of technological changes makes older literature irrelevant. As part of a record keeping system, folders were created for collation of all the data found (Siddaway et al., 2019).

Table 1

Inclusion and Exclusion Criteria

S.No.	Inclusion Criteria	Exclusion Criteria
1	Literature published in or after 2006. This research pertains to technology which changes very fast, hence older literature may not be relevant. (Older documents identified from bibliography may be used if found relevant)	Literature published before 2006. (Older documents identified from bibliography may be used if found relevant)
2	Published in English	Published in any language other than English
3	Articles published in peer reviewed journals	Articles not published in peer reviewed journals
4	Articles related to autonomous shipping and autonomous systems in aviation industry	Articles not related to autonomous shipping and autonomous systems in aviation industry
5	Contemporary study	Duplicate study

3.2.3 Searching or identification

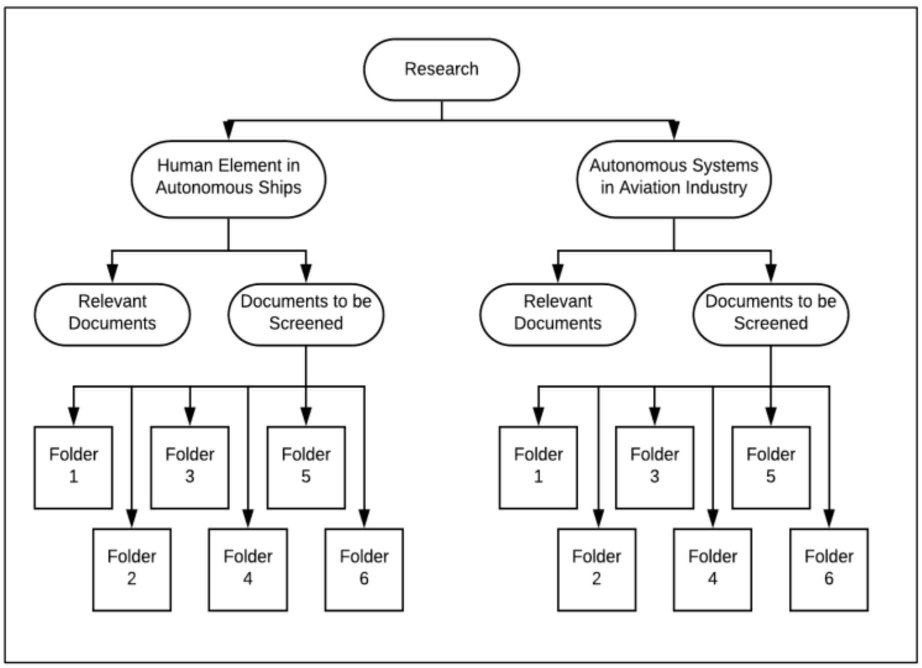
At this stage, the intention was to find all the peer reviewed published literature that pertains to the research questions using the identified search terms. Electronic databases were used for searching literature with the search being focused and narrowed using Boolean search operators 'AND' 'OR' and 'NOT'. Electronic databases used were EBSCO host, Directory of Open Access Journals, Science Direct, Science Open, Worldwide Science, Google Scholar, Microsoft Academic, Semantic Scholar, HCI bibliography, JURN and Sparrho. Further, the primary search was complimented by further searching reference lists and bibliographies of the documents found earlier. Thereafter, a random examination of the search results was done to ascertain reliability of search terms used for finding the relevant articles. In this case the search results were found relevant. However, in the event that this had not been the case, the next step would have been to reassess and/or change the search terms as well as the inclusion and exclusion criteria and the process would have had to be restarted from the planning stage (Siddaway et al., 2019).

3.2.4 Screening by 'Scaled-back Delphi Method'

Literature found after the initial search was screened for inclusion in the research. To reduce personal bias and subjectivity during the screening process, a screening process was incorporated in the methodological process referred to here as a 'Scaled-back Delphi Method' (Chalmers & Armour, 2019). A panel was formed, which consisted of six experts from the maritime industry with experience in different maritime aspects and representing different geographical regions. A process flow was created to ensure total anonymity of individual responses of all the panellists. To facilitate the screening process, folders were created on a Google drive as shown in Figure 1, and access was given to all the six panellists. Further, an email was sent to each member detailing the screening process. All the literature (full text documents) obtained after initial search were divided into six parts and each part was added to one of six folders under a 'documents to be screened' folder. Each panellist retrieved all the documents in any one folder and screened them as per the applicable research question. Thereafter, all the literature found relevant by each panellist was added by them to 'relevant documents' folder and all non-relevant documents were discarded. This process not only ensured anonymity but also ensured that there was no individual bias during the initial screening process.

Figure 1

Scaled-back Delphi method screening process



3.2.5 Eligibility

At this stage, the search focus shifted from sensitivity to specificity, where full text versions of relevant articles were read to ascertain if they were indeed relevant to the research or not. Once it was ascertained that the particular work was relevant for the research, all its relevant data was extracted (Siddaway et al., 2019).

3.2.6 Method for qualitative research synthesis: Qualitative Interpretative Meta Synthesis

At this stage, all the literature that was extracted was synthesized. Qualitative synthesis is a methodology where existing studies are analysed and interpreted to represent a collective meaning of the studies (Bearman & Dawson, 2013). Qualitative Interpretative Meta Synthesis (QIMS) was chosen as the method of choice for qualitative synthesis, as it synthesises groups of studies on a subject to form an enhanced understanding of the topic. Thereafter, it analyses individual research and utilises the information to create a web of knowledge about the topic where synergies amongst studies create a new and deeper understanding of the topic (Aguirre & Bolton, 2014). Qualitative data analysis and synthesis of data was carried out using MAXQDA which is a Computer Assisted Qualitative Data Analysis Software (CAQDAS).

Synthesis: Is a process where initial themes are identified in different literature or studies. Thereafter, the identified themes are integrated to form a deeper understanding of the topic. Integration of themes rather than studies ensures that integrity of each study is maintained and at the same time allowing synthesis of similar themes (Aguirre & Bolton, 2014).

Synergistic Understanding: This is the final stage where, based on the synthesis of studies carried out, conclusions, theory and implications are generated (Aguirre & Bolton, 2014).

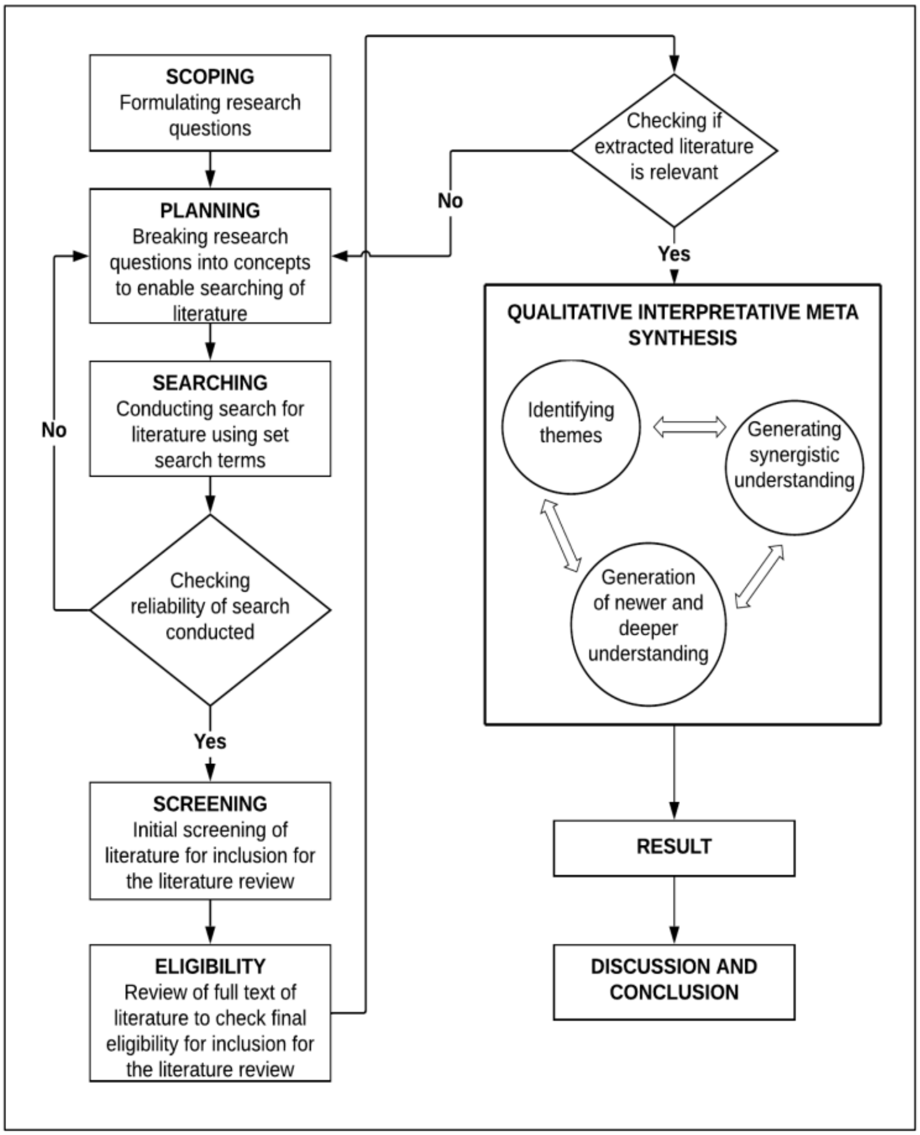
MAXQDA: It is a computer assisted qualitative data analysis software (CAQDAS), which provides methods for systemising, organising, and analysing non-numeric data. MAXQDA was used for organising various literature of similar content, which led to the formation of themes. Thereafter, the themes were structured, and all data was coded as per those themes. All literature, with respect to the individual themes, was then analysed for synthesis to develop a synergistic understanding of each theme. Subsequently, synthesised literature along with synergistic understanding led to formation of results of this research.

3.3 Research methodology flow diagram

The process flow of this research, which was conducted using SLR method and the synthesis, which was done by QIMS methodology using MAXQDA software, is as shown in the Figure 2.

Figure 2

Research Methodology Flow Diagram



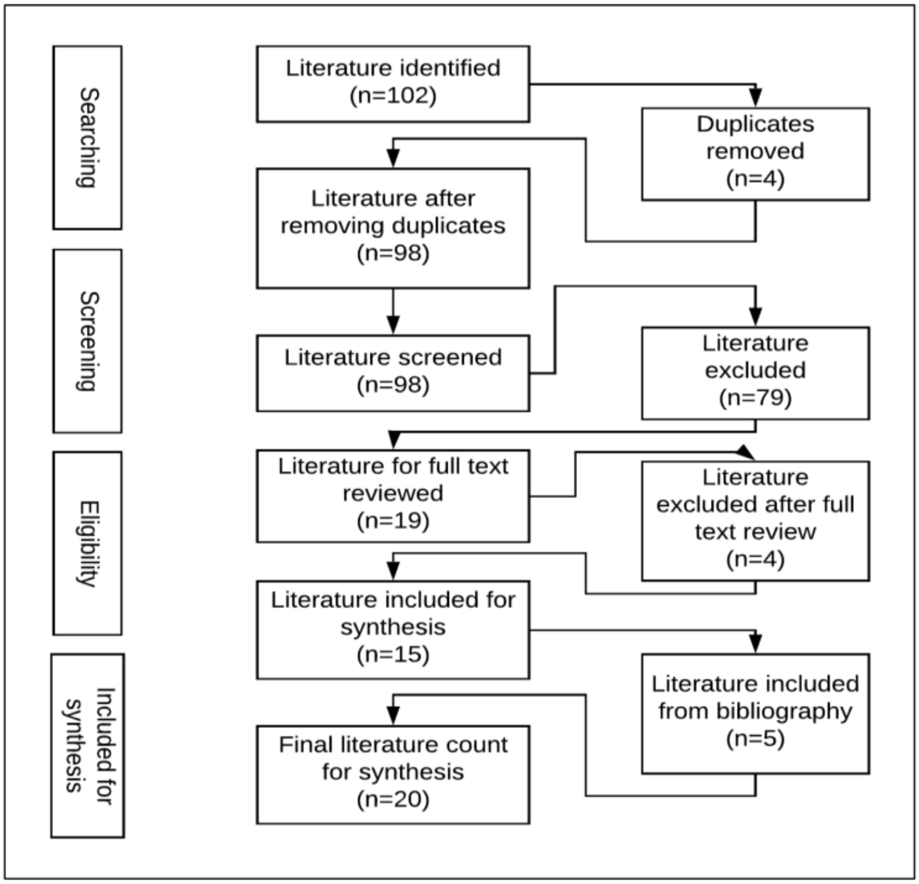
4 Research Results

4.1 Literature selection process for the analysis of human factors affecting the autonomous ship operations

The workflow and details of the literature selection process adopted for the research question pertaining to human factors affecting the autonomous ship operations are indicated in Figure 3.

Figure 3

Flow chart regarding literature selection process of human factors affecting the autonomous ship operations.



4.2 Research findings pertaining to human factors affecting the autonomous ship operations

As discussed in chapter 3, the research was conducted using SLR method, with synthesis done using the QIMS technique, and aided by MAXQDA, a quality data analysis software. In the QIMS stage, the synthesis/analysis led to the identification of the following themes: autonomy and automation, human errors, human factors causing human errors, and effect of human factors on autonomous systems. The synthesis of the literature reviewed under these themes resulted in the emergence of the following human factors which are deemed to pose a significant risk to autonomous ship operations.

4.2.1 Situational awareness

Situational Awareness (SA) is defined as: "*The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (Endsley, 1995a)

Situational Awareness (SA) may be divided into three levels:
Level 1 – Perception of elements in the environment
Level 2 – Comprehension of present situation
Level 3 – Projection of future scenario

Endsley's (1995a) model of SA is considered to be extensive and is the most cited model. However, components of this model have been challenged by theories suggesting that the three levels of SA are linear (Salmon et al., 2012), rather than ascending levels of SA as described by Endsley; that the model is limited to information processing and is data driven (Salmon et al., 2012); that the model is not dynamic (Salmon et al., 2007); that the mental models pertaining to SA are held in working memory and not in long term memory as suggested by Endsley (Chiappe et al., 2012). However, by objective and substantive research findings, the criticism to Endsley's model is proven to be inaccurate and a better understanding of the aforesaid model has evolved with time (Endsley, 2015).

Memory, attention, and perception remain the biggest challenges in acquiring SA (Kristoffersen, 2020). Lack of the feel of the vessel i.e. lack of 'ship sense' results in inadequate SA. Remote operators in the context of autonomous ships would have access to the vessel information at the SCC. However, the lack of 'ship sense' and their reliance on their memory and attention for absorbing vessel information and data, may cause them to experience cognitive overload while developing or maintaining the SA (Hogg & Ghosh, 2016).

In order to overcome challenges to obtaining SA, autonomous system design should be such that it can factor in SA issue like fatigue, attention tunnelling, memory traps, data overload, anxiety, etc. and as far as possible should use both audio and visual tools for displaying the information, as these help in the building of mental models of the process, which is considered as one of the better ways to comprehend and retain information. Further, systems should be designed such that they are able to provide data which would in some ways be able to compensate operators' lack of ship sense and aid operators to gain a full picture especially during high workload periods (Kristoffersen, 2020).

4.2.2 Cognitive factors – Mental workload

Higher cognitive demands during remote operation of autonomous ships accentuate the requirement for proper understanding of how mental workload affects the remote operator of an autonomous ship. Mental workload would depend on factors such as the operator, the task, and the environment (Hogg & Ghosh, 2016). It has been found that increase in mental workload increases the complexity of the cognitive task (Boag et al., 2006). Furthermore, it has also been found that mental underload affects human performance just as much as mental overload does and causes errors, distractions, and decrease in performance (Young et al., 2015). With the increase in environmental demand, mental workload increases, causing cognitive strain on the operator, as humans have limited capacity to process large amounts of data and information. On the contrary, when environment demand is low, operator tends be less vigilant and less focused due to a lack of mental stimulation, and this stage also causes errors to creep in. Thus, it is inferred that optimum levels of performance are achieved during intermediate levels of mental workload. Reduced performance is observed during higher and lower levels of mental workload (Tavacioglu & Özsever, 2019).

Hence, it is of utmost importance that autonomous vessel shore control centres (SCC) are designed such that the mental workload of the operator is well distributed to ensure that higher or lower levels of mental workload are avoided and that optimum levels of mental workload are maintained throughout.

4.2.3 Cognitive factors – Data overload

Autonomous vessels, in addition to a whole range of remote sensing equipment would also have a plurality of sensors fitted on the autonomous vessels themselves. Due to the high level of automation and autonomy, remote operators would have access to excessive information and not all of this available information would be required by them for developing the required situational awareness and understanding of what is going on in the environment around the vessel. This problem of excessive information would be accentuated if the operator is overseeing the navigation of multiple vessels, in which case he/she would be required to switch between different vessels. This would not allow him/her to gain adequate situational awareness of any vessel being monitored (Porathe et al., 2014).

One of the solutions for this issue is to opt for sensor fusion where output from different sensors is moderated prior to being available to the operator. However, this also has its flaws as operators may want to know what is the output of each sensor and there may be cases where a sensor may start malfunctioning, in which case the operator would need to identify the failing sensor immediately and sensor fusion may not aid that. Hence, sensor fusion should be done such that the system remains transparent to the operator but without inducing information overload on the operator.

4.2.4 Technology factors – Automation-induced complacency

Increase in automation has changed the role of an operator from being the main operator to a passive observer. Highly automated systems foster complacency resulting in errors as it induces feelings of satisfaction causing decreased vigilance. In effect, it leads to operators not adequately monitoring systems, using single sources of information, bypassing procedures, following incorrect practices, overlooking important signals, and misinterpreting data, etc. Consequently, a potentially dangerous situation being developed may be missed resulting in disastrous consequences. One of the factors that induces this complacency is the false sense of confidence that the system will not make mistakes, especially if the system has been operating satisfactorily for a considerable period of time (Bielić et al., 2017). Automation-induced complacency is directly affected by the training received by the operator, workload experienced, and reliability of the system (Dreyer & Oltedal, 2019). Further, it has been found that automation-induced complacency is not affected by experience or practice, and both experienced and naive operators are prone to it (Hogg & Ghosh, 2016).

4.2.5 Design factors – Out of the loop syndrome

Out of the loop syndrome occurs when an operator is not in synchrony with what the autonomous system is doing or his/her attention is on some other task thereby missing important information and resulting in lower SA (Endsley & Jones, 2012). It has been found that out of the loop syndrome is also linked to two significant issues i.e. loss of skills and the loss of system awareness, and these adversely affect operators decision-making ability in case of any failure or emergency situation (Endsley & Kiris, 1995). Furthermore, in addition to understanding human abilities and characteristics in this regard, this aspect also questions the ability of humans to supervise and act as backup to autonomous systems (Dreyer & Oltedal, 2019).

Accordingly, the design of the autonomous systems should be carefully done so that, they are able to overcome all the factors which would put an operator out of the system information loop. The system should not only be extremely interactive but also ensure that the system feedback or information is received and understood by the operator. The system should also be able to prioritise information processing and display, to ensure that all the relevant and useful information gets conveyed to the operator without any delay.

4.2.6 Design factors – Skill degradation

Manual operation skills deteriorate when not used. Hence, due to reliance on automated systems and without adequate experience of operating the system manually, operator skills required for handling the autonomous system especially in critical situations is diminished. Research in cognitive psychology has found that forgetting and skill decay occurs due to disuse (Rose, 1989). Experiment conducted by Peterson and Peterson showed increased decay of memory trace with increasing time interval (Peterson & Peterson, 1959). Degradation of cognitive skill is of a concern, particularly following an automation failure, where the operator may not be skilled enough to operate the system manually or take critical decisions required under those circumstances. Studies have found that human response to a system failure is better for a system which has intermediate level of decision-making, when compared to a system which has a higher level of decision-making (Parasuraman et al., 2000).

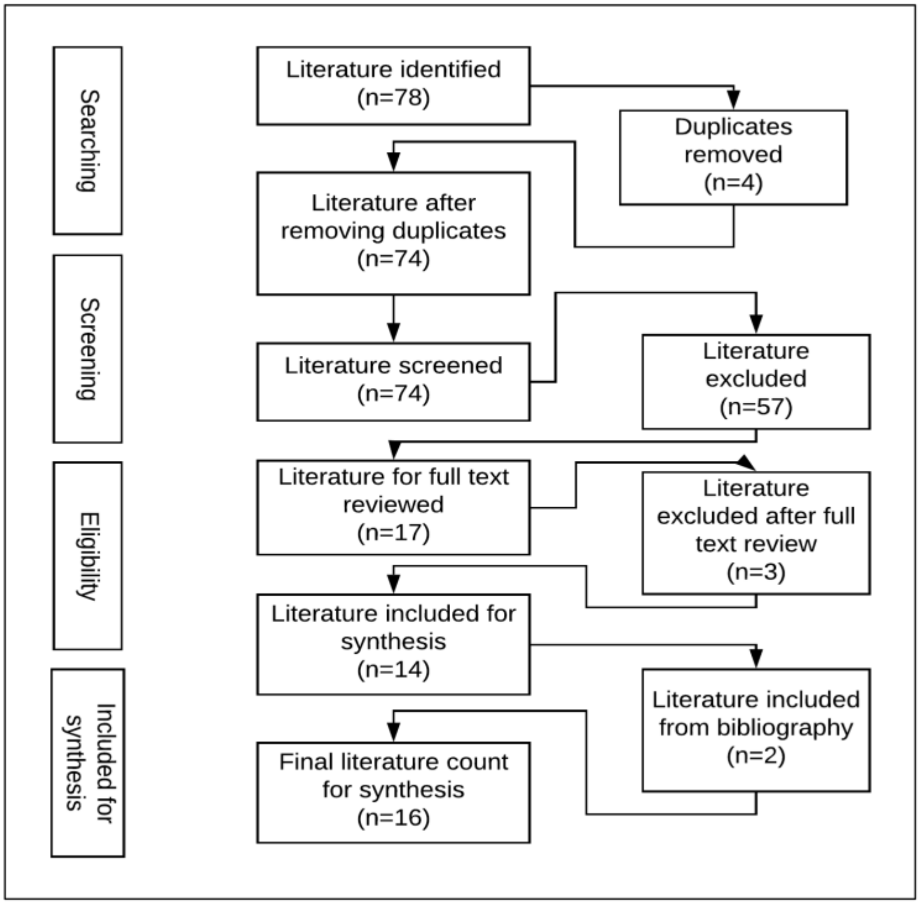
One way of overcoming this is by incorporating 'resilience engineering' which means that the safety of a system is measured not just by the lack of the accidents it has enabled, but also by its ability to perform successfully under various different conditions (Hollnagel, 2014). It is easier and effective to enhance safety by increasing things that go right rather than decreasing things that can go wrong. This may be achieved by enhancing positive capabilities of people, that would enable them to adapt effectively to different situations under pressure (Dekker et al., 2007).

4.3 Literature selection process for the analysis of human factors affecting the remotely piloted aircrafts

Workflow and details of the literature selection process adopted for the research question pertaining to human factors associated with remotely operated aircrafts are indicated in Figure 4.

Figure 4

Flow chart regarding literature selection process of human factors affecting the remotely piloted aircrafts



4.4 Research findings pertaining to human factors affecting remotely piloted aircrafts

Similar to the process used for the SLR and to analyse the literature on human factors related to autonomous ships, this phase of the analysis on the literature on human factors related to remotely piloted aircraft also followed the SLR method, a QIMS synthesis technique using MAXQDA. The synthesis/analysis led to the identification of the following themes: autonomy and automation, human errors, human factors causing human errors, effect of human factors on autonomous systems, and guidelines to control human factors. The synthesis of the literature reviewed under these themes resulted in the emergence of human factor issues which pose a significant risk to the operation of remotely piloted aircrafts and the measures adopted by the aviation industry to control the identified human factors.

4.4.1 Situational awareness

Situational awareness is affected by lack of conscious and subconscious cues. Remote flying experience is quite different from conventional flying, as the RPA pilot lacks physical cues such as motion, feel, visibility, sound, and smell. In addition to the lack of these important physical cues, lack of vestibular cues like motion and sink rate are also equally responsible for the RPA pilots not being able to attain adequate situational awareness. It is observed that situational awareness is a particularly important aspect in RPA operations especially during landing, as a remote operator does not get a direct view of the runway until the final approach. RPA pilot instead of getting cues from various available environmental factors within the cockpit, gets to look at a map screen showing a moving icon which represents the aircraft. Loss of situational awareness is exacerbated by the physical distance between the remote pilot and the RPA, which causes system latencies, even a delay of one second or more not only create temporal and spatial uncertainties, but is also responsible for image update lag time. All these factors impose extra mental processing requirements and adversely affect the operator's ability to build and maintain an appropriate mental model of the current situation. Reduced situational awareness leads to aircraft accidents as it causes failure in correctly perceiving information, failure to comprehend and integrate information, and failure to project future scenarios (Merlin, 2013).

On conventional flights, pilots make errors quite a few times, but these get identified and are corrected by the pilots themselves before any damage is done. However, remotely located pilots, due to them not being co-located on aircrafts find it difficult to correct their self-errors. Lack of out of the window view has an adverse effect not only upon collision and traffic avoidance measures, but also during taxing, take-offs and landing phases (Hobbs & Lyall, 2016).

One of the means adopted for enhancing operator's situational awareness during RPA operations is by adopting 'detect and avoid' (D&A) systems for traffic avoidance and mid-air collision avoidance. In traffic avoidance phase the operator can choose a manoeuvre. However, in collision avoidance phase the system initiates the manoeuvre automatically. The system also provides the information of the intruding aircraft i.e. if it is equipped with a transponder or not and thereby it helps the remote pilot understand what information of the intruder aircraft is available to other stakeholders such as Air Traffic Control Officers (ATCO). The D&A system ensures the availability of collision avoidance systems even when there is breakdown of the data link between the pilot and the RPA (Alfredson et al., 2015).

Another method adopted to increase situational awareness of RPA pilots is by using haptic aiding concept, wherein similar to a conventionally piloted aircrafts, any external disturbance or a fault effecting the aircraft aerodynamics, produces a perceptible effect by force feedback upon the control sidestick. This serves to cause the pilot to look at the instruments to understand the current situation. This also ensures that the pilot feels the load factor and is able to avoid conditions which may take the aircraft towards the boundary of its operating envelope or which may be dangerous to the aircraft's structure (Alaimo et al., 2010). There are several other methods which are adopted to overcome RPA pilot's situational awareness deficiencies. Situational awareness is enhanced by use of multimodal control interface with alarms, warning lights, and touch-based systems with vibration type feedback. The aim is to reduce the operator's mental workload and thus enables increased efficiency and flight safety (Merlin, 2013).

4.4.2 Cognitive factors – Workload

A pilot's workload depends on the task demands and required human response to these task demands. Regarding RPA pilots, workload depends upon the type of the aircraft, level of autonomy and automation, and the mission of the aircraft. Long range flights have long periods of low workload, where the pilot is engaged mainly in navigation and monitoring the health of the system. All flight operations have short periods of high workload mainly during taxiing, take-offs, landings, and during high density air traffic conditions. Furthermore, an RPA pilot's workload increases when any malfunction is experienced or when experiencing heavy weather conditions. RPA pilots' work start with preparations for the flight which includes checking notices to airmen, checking current weather, conducting crew briefings, etc. Thereafter, flight operations commence once the RPA is airborne after taxiing and take-off. The pilot must ensure that the aircraft remains clear of no-fly zones and must give his/her full attention to all aircraft parameters such as airspeed, altitude, headings, communication, and the aircraft configuration. During landings and take-offs pilots perform multiple operations simultaneously within a short span of time. For example, during landings, RPA pilots control the throttle to check the airspeed and intersect with the Global Positioning System (GPS) landing system localiser, while selecting a reference point on the runway and then finally executing the landing flare with required airspeed and throttle position for final touchdown. All these task demands in a short span of time leads to high workload on the RPA pilots (Merlin, 2013).

Automation is one of the steps taken by the aviation industry to manage the RPA pilot's workload. However, while automation does reduce a pilot's workload to some extent, it also brings in several other problems. Some of the problems that automation poses are loss of expertise and complacency resulting in operator not being able to pick up system errors. Studies have shown that many times automation rather than reducing the workload, actually redistributes the existing tasks and also introduces new and different tasks (Merlin, 2013). One of the successful ways of embracing automation in the aviation industry has been by incorporating information integration systems such as Electronic Centralised Aircraft Monitor (ECAM), which was adopted by Airbus and Engine Indicating and Crew Alerting System (EICAS) which was incorporated by Boeing. Complex operations of a fully automated flight deck are alleviated by incorporating ECAM and EICAS, where a simple user interface allows the operator to monitor the system and tackle the system issues. Such issues are captured and highlighted on the screen by way of warnings and alarms, thus aiding the pilot's decision making process (Brown, 2017). To reduce the RPA pilot's workload some RPA systems, use external pilots, who are responsible for taxiing, landings, and take-offs. External pilots are positioned at the airports and maintain visual contact with the RPAs. This system involves transfer of the RPAs control between RPA pilots and the external pilots (Merlin, 2013).

4.4.3 Technology factors – Automation induced errors

The aviation industry has experienced quite a few accidents which happened due to the use of advanced technology and autonomous systems on board. In one of the accidents (Oliver et al., 2017), the aircraft's computer activated a stall warning about 75 times in about four and a half minutes from when the autopilot was disengaged till the aircraft hit the water surface. However, none of the pilots, including the captain, understood that the aircraft was actually in the stalled state. In that aircraft (Airbus) automation was designed such that a stall warning gets cut-off when the aircraft is below a certain airspeed. In this case, abnormal angle of the aircraft during its uncontrolled descent caused airspeed to be shown as less than what it actually was and this anomaly caused the aircraft's airspeed to be indicated as below the level where the stall alarm gets cut-off. Hence even though the aircraft was in the stalled state, the stall alarm was not activated. When the pilots tried to increase the speed of the aircraft, the airspeed would then increase and come in the range where the stall warning gets re-activated and this enabled the stall alarm. This activation of stall alarm upon increasing of the speed created confusion amongst the pilots who could not understand how the speed increase was causing the aircraft to stall, however in reality this was not the case as the aircraft was already in the stalled condition, though the stall alarm was not activated as airspeed indicated was below the threshold level for stall alarm activation. The situation was grave and required recovery procedures to be initiated immediately, by increasing the aircraft speed. The required recovery action was not taken by the pilots as the aircraft's stall warning gave a wrong indication of the aircraft's actual status, resulting in the aircraft crashing. Hence, in this case, technology which was designed to help the pilots prevented them from understanding the situation and taking the right action. There are other accidents (Johnston & Harris, 2019) where a newly introduced system i.e. Manoeuvring Characteristic Augmentation System (MCAS) caused the plane to stall and ditch, and pilots were not aware of how to override MCAS. There are numerous accidents in the aviation industry, including with RPAs, which were caused by technology originally intended to aid the pilot and ensure safe operations (Evjemo & Johnson, 2019). It should be noted that conventional aircrafts have the ability to turn off automation or reduce the use of automated system and engage manual control of the aircraft. However, most RPAs rely on automated and autonomous systems for basic flight control and RPA pilots mostly play a supervisory role (Hobbs & Lyall, 2016).

The aviation industry has taken steps to counter the technology induced errors by adopting a risk-based strategy, which follows risk management principles of prevention, correction, and containment. The prevention stage is during the design phase, where all unexpected system behaviours are anticipated and then appropriate barriers (maintenance policies, supervisory controls, procedures, training etc.) are installed to mitigate the identified risks. The correction stage is for when the preventive measures adopted fails. Here, the system is designed to detect these unexpected and abnormal conditions (alarms, etc.) and measures are incorporated within the system to counter those conditions (emergency brakes, etc.) if they occur. The containment stage is when the corrective action also fails and an accident does happen, this is when the steps are taken to minimise the consequences of the accident (Millot & Boy, 2012).

4.4.4 Design factors – Human machine interface

Human Machine Interface (HMI) refers to the medium where information is exchanged between human users and the system, and also the way the information exchange takes place between them. Hence, human machine interfaces and the interactions at the interface are the key aspects of HMI design. HMI design is mostly associated with display characteristics, content format, timing and duration of information presented, modality of user inputs to the system, etc. Design of the HMI is mostly related to the process and the information flow of the system and adaptations for the user inputs including external conditions. Since HMI involves large amounts of data, its design should consider human limitations regarding information processing. A well-designed HMI enables users to gain trust in systems having higher level of autonomy, thereby increasing system performance in terms of efficiency and safety (Lim et al., 2018).

Investigations of various RPA accidents reveal that most of the accidents attributed to human error are the direct result of design issues related to HMI. In the aviation industry, HMI is continuously evolving and maturing with time as it constantly improves design shortcomings of the past. All HMIs are now designed such that they consider human factors, thereby increasing their efficiency and safety. HMI design must consider operators cognitive tunnelling i.e. attention getting focused on one task to the detriment of other tasks and information. When operator gets back his attention, the system should aid him in getting the RPA status immediately. Information provided should not make the remote pilot overloaded but should ensure that all the required information is available to him/her and he/she is able to maintain adequate situational awareness at all times. Remote pilot station HMI design should be sufficiently forgiving to avoid a loss of RPA in case RPA pilot misses making a critical control input. Mostly RPA pilots are in supervisory control, which means that the human operator gives the command and the machine carries out the task autonomously. This may include having HMI to start-stop the engine, navigation between the waypoints, changing the air speed and altitude, changing the mission, etc.

The Global Hawk System is one example of a system which provides supervisory control to the RPA pilots (Merlin, 2013).

4.4.5 Personal factors – Training and Knowledge

The aviation industry has realised that good knowledge, training, and teamwork are a must for sustainable growth of RPAs. However, numerous RPA accidents have taken place where the root cause has been identified as inadequate knowledge and training, failure to follow established procedures and a lack of staff coordination. One such incident was where during the handover process between the two ground stations, while executing the handover, one RPA pilot inadvertently turned off the RPA's engine and stability augmentation system, leading to its crash. In another incident, during landing the RPA crashed 300 feet short of the runaway as its remote pilot did not follow the landing checklist and failed to disengage autopilot's airspeed hold mode. In yet another incident, the pilot accidently switched off the stability augmentation system causing the RPA to dive. Thereafter, he did not follow the recovery procedures correctly, resulting in the loss of the RPA. These incidents reiterate the importance of having trained, knowledgeable and competent manpower for RPAs (Merlin, 2013).

For an effective training regime, it is required to have experienced instructors, well-defined standards, and robust assessment and evaluation processes. The aviation industry has adopted simulation and visualisation techniques where students have to fly procedures in their minds, which means training in an environment similar to the work environment. Students carry out procedures and flying circuits repetitively so that the skill gets embedded as part of their muscle memory. This helps in gaining situational awareness and enhancing cognitive functions especially when encountering an emergency or an unforeseen situation. Studies have indicated that training by visualisation along with practical training can achieve same results as those on continuous on-the-job functions. Simulation based training is one of the efficient training methods which uses visualisation techniques, where different real situations can be simulated for training without exposing persons to the associated real dangers (Baldauf et al., 2012). The aviation industry uses this philosophy and their training involves visualisation and simulation techniques, which are followed by occasional manual flying to ensure necessary skills get embedded (Brown, 2017). Furthermore, ICAO has recommended that in addition to the RPA pilot there should also be an RPA observer who would help the pilot in the overall monitoring of the system (ICAO, 2015). ICAO has also published guidelines for certification and competence required for the RPA pilots and the RPA observers, thereby institutionalising the certification process for both remote pilots and observers (ICAO, 2015).

4.4.6 Physiological factors – Stress and Fatigue

Stress may be defined as a feeling of emotional or physical tension (U.S National Library of Medicine, 2020). Stress is a body's reaction to any change that requires adjustment or response, and the body reacts to these changes with physical, emotional, and mental responses. Within limits, stress may be positive when it helps in avoiding danger, inducing alertness, keeping motivated, etc. However, stress becomes negative when a person is exposed to challenges without any respite or break. As a result, the person becomes overworked and stress-related tension builds up leading to physical and emotional drain-out (Cleveland Clinic Medical Professional, 2015).

Fatigue is a term used to describe a feeling of tiredness or lack of energy. When fatigued, a person has no motivation or energy to perform the task. Sleepiness is only one of the symptoms of fatigue (Healthline, 2020).

Insufficient sleep, prolonged work hours, rotational shift-work, anxiety, etc. may cause fatigue and stress in RPA pilots. The human body follows a circadian rhythm which may be disrupted by rotational shift-work schedules and prolonged work hours leading to stress and fatigue. Studies have shown that RPA pilots are more prone to stress than conventional aircraft pilots (Merlin, 2013). Conventional aircraft pilots use traditional methods of aircraft control like control stick, rudder pedals, engine throttle, for different flying operations like adjustments to engine power, change in altitude, change of heading, etc. In conventionally piloted aircrafts, the pilot's decision is supported by the feedback available in the aircraft. However, RPA pilots - due to a lack of feedback and availability of only a camera view - are likely to become task-saturated, as their attention is divided between executing a task, assessing the response of the aircraft while maintaining situational awareness, verifying the actual response of the aircraft through different sensors, and then applying corrective action if required. All these tasks require concentrated visual attention to multiple sources of information and this induces stress and fatigue in the RPA pilots (Merlin, 2013).

Strategies adopted by the aviation industry to manage fatigue include ensuring quality and adequate quantity of sleep for RPA pilots. Rotational work-shifts, where required, are to be not more than eight hours in a day. Human centric workstations, that ensure among other things, minimum glare and strain on the eye, as seen by use of blue light at the RPS, with controllable intensity to reduce fatigue. Research has shown that blue light has a positive effect on individual alertness, job performance, and mood. There is also controlled usage of caffeine, nicotine, and other beverages for controlling stress and fatigue, as misuse could have detrimental effects on the individual (Scheiman et al., 2018).

5 Discussions, Recommendations and Conclusion

5.1 Discussions and Recommendations

This section discusses the research results while carrying out a comparative analysis of human factors in the context of autonomous systems in the aviation and maritime industries. It thereby discusses appropriate measure to be adopted by the maritime industry to optimally address human factors in the development and adoption of autonomous systems. The analysis of the research findings on both autonomous ships and RPAs shows that some of the human factors identified are the same for both industries, while some are applicable only to one of them. The main reason for this difference is the different operational requirements of the respective industries and the fact that the aviation industry may be argued to be ahead of the maritime industry in the adoption of autonomous technology. This is the reason that, unlike for RPAs, the research results for autonomous ships, do not show any concrete measures adopted for controlling the identified human factors.

Similar to the aviation industry, automation in the maritime context presents both advantages and challenges. Some of the advantages in the maritime context are the availability of more reaction time due to slower speed of ships and the ability of ships to stay afloat or maintain position without much efforts. One of the most prominent challenge amongst others, is the large inertia of the ship, due to which collision avoidance manoeuvres must be made well in advance for them to be effective. In regard to port arrival, departure and between port transits, both aircraft and ship workload increases and they have restricted manoeuvring space during port arrival and departure, while they have ample manoeuvring space when transiting between the ports. These aforementioned factors, amongst others, have been considered while recommending measures to control human factors in autonomous ship operations.

5.1.1 Situational awareness

The research results clearly show that in the case of autonomous ships, remote operators' lack of ship-sense would cause them cognitive strain while gaining or trying to maintain situational awareness during remote operations. The situation is no different from what pertains in the aviation industry where RPA's pilot also experiences loss of situational awareness due to remote location of the control station. However, since RPAs are already integrated in the aviation industry, factors leading to loss of situation awareness are clearly identified and measures adopted to deal with them. The main causes identified for the loss of situational awareness is the remote location of the operator which not only brings in the latencies due to distance but also affects spatial uncertainties. Furthermore, the lack of local environmental cues increases cognitive stress on the remote operator.

To deal with the lack of situational awareness, the aviation industry is using multiple sensors and sensor fusion technology to ensure accurate creation of a map representing the local environment around the aircraft. In addition, they are using the haptic aiding concept to provide feedback to the remote operator regarding any aerodynamic changes around the aircraft. Further, it uses 'detect and avoid' technology as a last line of defence to avoid collision in case everything else fails. Equipment interfaces and technology being used are maturing with time as the industry moves toward adopting fully autonomous technology.

The following is recommended to ensure adequate situational awareness is always maintained on the autonomous ships:

5.1.1.1 Optimum level of human interface

One of the key elements to aid an operator's situational awareness in an autonomous system is the definition of the level of operator's interaction with the system's decision-making process. The operator should not be overloaded by getting him/herself involved in most of the system decisions nor should he/she be left out of the processes which involve critical decisions. Optimally balanced human involvement in the autonomous system remains the key, to ensure the operator maintains adequate situational awareness at all times (Parasuraman et al., 2000).

5.1.1.2 Real time hull stress feedback system

To compensate for the lack of ship sense, hull stress monitoring system which calculates real time stresses on the hull during bad weather, cargo operations etc. may be installed on autonomous ships and its output be sent to the SCC by a proportionate force and vibrations feedback mechanism to the control stick. To a degree this could ensure that the remote operator gets a feel of the forces acting on the ship's hull, and thereafter detailed data can be obtained to get actual information on the conditions around the ship, this is a must to ensure that the action taken by remote operator is appropriate to the prevailing conditions around the ship.

5.1.1.3 Reliable sensor and sensor fusion technology

Presently there is no single sensor technology that can operate in all possible conditions such as, rain, fog, day, night, etc. Hence, diverse types of sensors must be used to ensure adequate data is obtained in all the conditions. Accordingly, sensor fusion plays an important role as multiple sensor data needs to be integrated to develop an accurate map or image of the remote conditions around the ship. There are different sensor technologies available, such as cameras (infra-red, near infra-red, longwave infra-red, shortwave infra-red), radar, light detection and ranging, acoustic, etc. Each of these technologies have their own strengths and limitations and the combination of these technologies must be used to ensure remote operators attain proper situational awareness of conditions around the ship at all times. The preferred combination of sensor technology that may be adopted is not within the scope of this research and would depend upon factors such as performance, reliability, and cost (Poikonen, 2016).

5.1.1.4 Collision avoidance module

This module is responsible for safe navigation of the vessel. As a last line of defence, when other factors fail, including loss of communication link with the SCC, autonomous vessels should be able to act well in time to avoid collision or grounding. Systems may be such that the map or image from sensor fusion showing dynamic objects or obstacles is superimposed upon electronic charts showing static objects and depths, enabling ship to take action as per collision avoidance rules and in relation to available water depths around the vessel.

5.1.2 Cognitive factors – Data overload and Mental workload

The research results show that 'data overload' and 'mental workload' are the cognitive human factors which effect the maritime industry and 'workload' is the cognitive human factor which effects the aviation industry. This distinct difference is because, in the case of the aviation industry, cognitive functions are mainly affected by the excessive 'workload' experienced by the pilots, which is mainly during landing and take-offs, where the pilots are required to perform multiple critical tasks simultaneously within a very short span of time. This condition is exacerbated for the RPA pilots, as besides those factors, they are also disadvantaged by being remotely located. In the case of ships, excessive 'workload' is not the same as that for aircraft, as even during high workload periods, i.e. during arrivals, departures, in congested waters, etc., shipboard workload is spread over a fairly long period of time and it is rarely that ship operators individually require multiple critical tasks to be performed simultaneously within a very short span of time. However, this refers to the peak/acute workload and does not deny the negative impact of chronic long-term workload which remains a significant factor at sea.

Due to difference in the nature of work of the RPAs and autonomous ships, 'workload' is not a prominent human factor issue affecting autonomous ship operations, as it is seen for RPAs. Furthermore, upon closer examination, it is observed that the 'mental workload' human factor, which is identified for the autonomous ship operations relates to the design of the SCC and the equipment therein, thereby aligning more with the human factors associated with 'data overload'. Hence, both these human factors i.e. 'mental workload' and 'data overload' are discussed here together, as both have similar mitigating measures.

Autonomous ships, depending upon the level of autonomy, would have a high level of automation and would be fitted with multiple types of sensors to ensure that adequate data is available to the remote operators, for them to develop and maintain the required situational awareness. Unless adequately mitigated, increase in the level of automation or autonomy brings in the problem of data overload which is not that easy to solve. The research results indicate that data overload is one of the prominent causes for mental workload, and that an intermediate level of mental workload is required to ensure operators' optimum performance. Hence, controlling the data overload would ensure that the operator is not subject to excessive mental workload.

Data overload can be put in three categories. To find appropriate solutions, it is important to understand these categories and the effectiveness of measures adopted under each of those categories. The first category is that of *too much data*. This refers to the condition where it is assumed that the system has excessive data and in this case the solutions are based upon the principles of filtering the data to reduce its content. However, the issue with this kind of approach is that the data which is filtered out may be useful or may be required in a different context. The second category is that of *workload bottleneck*. This is when there is too much data to be processed within a given time frame. The solution here is based upon the principle of using automation for data analysis. However, research indicates that automation is not always the best solution as it comes with its own problems and its hurried introduction may create new roles, new requirements, new demands, etc., all of which may not be aligned. Hence measures adopted may have little positive effect and result in clumsy automation with no real value addition. The last category is that of *finding the significance in data*. This refers to model-based organisation of the data, which shows its relationship with various informative parameters involved and the use of artificial intelligence to aid the user in selecting, managing, and interpreting the data. The advantage of this method is that no data is filtered out, all the data is processed and is available to be used by the user in the context of the prevailing or upcoming circumstances (Woods et al., 2019).

After discussing the different approaches to solve the data overload problem, the following is recommended based on 'the significance in data' approach to minimise data overload and to keep mental workload to intermediate levels. This approach is also adopted by the aviation industry, where they have integrated systems like EICAS and ECAM.

5.1.2.1 Model-based representation

In this model, a relationship is defined based on the process and activity function. These also form the basis for giving meaning to the data. Artificial intelligence is used to generate event-based displays which capture the flow of the events or generate expectation-based displays which highlights when an event deviates from the set parameters or expected behaviour. This system enables generation of multiple displays, each of which defines a perspective on the field of data. Such a system would need a mechanism to help the user coordinate between different sets of displays (Woods et al., 1999). Without going into the technicalities of the data/sensor fusion technology available today, the idea is to be able to use heterogeneous sensor data from multiple sources, without initial filtering to ensure that all the data contributes towards the development of a representative model/picture of the remote environment. This model/picture would aid the operator in attaining all the information available without being overloaded with excessive data. Further, the user interface required would ensure required level of mental workload for optimum human performance.

5.1.3 Design factors – Out of the loop syndrome and skill degradation

Careful analysis of the two identified human factors i.e. 'out of the loop syndrome' and 'skill degradation' indicate that both are closely interlinked, as out of the loop condition causes skill degradation. Therefore, mitigating measures of one would have a positive effect on the other. Hence, both these factors are discussed together.

Out of the loop syndrome leads to user's performance degradation due to disengagement from the process. Indicators of this include operator attention lagging behind the system processes, feeling surprised at the occurrence of events, experiencing a feeling of tiredness, suffering constant distraction, etc. These conditions push the user out of the system loop (Kontogiannis & Malakis, 2009). The condition is a major issue associated with autonomy and automation. There have been about twenty-six aircraft accidents in last five decades which have been attributed to technology and human factors (Gawron, 2019). Pilots' inadequate monitoring of automated or autonomous systems remains an important issue, where operators often act as mere monitors and are unable to detect system errors or take significant amount of time to detect an error. This delay in the detection of error, prohibits operators from taking an appropriate action or it lessens the effectiveness of actions, if taken (Endsley, 1995b). This research indicates that 'out of the loop syndrome' has not come up as a significant factor effecting RPA operations as autonomous technology in the aviation industry is maturing and evolving, and this factor is now well understood and effective control measures are incorporated.

Automation is classified as '*static automation*' and '*adaptive automation*'. Static automation is a fixed level of automation which is either switched on or off i.e. 'either it is there, or it is not'. The advantage of static automation is that it reduces operator's workload. However, research on human interactions shows that it has brought in some disadvantages also i.e. manual skill degradation, monitoring inefficiency, complacency etc. In contrast, adaptive automation is less vulnerable to these issues as it enables automation to be adjusted dynamically depending upon the task demand on the operator and the task difficulty level. This approach has numerous benefits including, ensuring optimum levels of operators' workload, preserving their skills, and ensuring appropriate operator engagement with the system. Adaptive automation has three main approaches for triggering the mechanism for adjusting level of automation or autonomy i.e. *critical-event strategy*, which is based on the assumption that human workload would increase when certain critical tasks happen. *Performance-measurement strategy* is based on the principle of estimating human workload based on operator performance during a task. Lastly *neurophysiological-measurement strategy* determines human workload based on operator's neurophysiological signals, mainly by using electroencephalogram (EEG) in a *brain machine interface (BMI)* (Aricò et al., 2016). Studies indicate that adaptive automation using EEG method leads to high levels of situational awareness and ensures appropriate levels of workload and engagement. Further, adaptive automation using EEG method has the ability to identify situations where it is better to shift the control to the operator, especially during underload conditions where monotony could set in, making the operator inefficient in detecting automation failures. However, adaptive automation using EEG method has its challenges as well, some of which are as follows. Though adaptive automation may relieve the operator from switching between autonomous and manual controls, it imposes additional monitoring tasks. Operators with inadequate training may not understand the functioning of the adaptive automation and under certain circumstances may consider its actions as erratic. Further, the reliability of adaptive automation systems depends on accurate measurement of the operator's state including physiological variables which may not be easily accessible under all circumstances. However, these challenges can be overcome by proper implementation (Lee & Seppelt, 2012). All the aforesaid strategies have their pros and cons. However, a neurophysiological strategy has advantages over others as due to its continuous output, it brings in another dimension of optimising operators performance by acting on certain observed behaviours of operators (Aricò et al., 2016).

The following is recommended for controlling the 'out of the loop syndrome' in autonomous ship operations:

5.1.3.1 Adaptive automation and autonomy

Adaptive automation leading to autonomy is recommended as it ensures that the operator is always in the process loop and his/her level of engagement is decided by the task workload and task difficulty level. This also ensures operator’s optimum engagement with the system, enabling him/her to develop and retain manual handling skills. Regarding the type of adaptive autonomy to be used, it may be noted that, presently ‘critical-event strategy’ and ‘performance-measurement strategy’ are in use in the aviation industry and now with rapid technological developments, experiments are being conducted for use of brain machine interface (BMI) in the aviation industry including for the RPAs.

In regard to autonomous ship operations, it is recommended that adaptive autonomy and automation, based on critical event or operator’s performance may be adopted. However, adaptive autonomy based on neurophysiological measurements i.e. BMI, needs to be studied and adopted in a phased manner. This would ensure that the required balance between human and technology is attained, as operator’s attention allocation plays a vital role in this approach. This approach also fosters a new concept of working arrangements between humans and the autonomous technology, thereby increasing collaboration between human-machine team (Pietschmann & Ohler, 2015).

5.1.4 Technology factors – Automation induced error

This research indicates ‘automation induced complacency’ as the human factor affecting autonomous ship operations and ‘automation induced error’ as the human factor affecting the aviation industry. Automation induced complacency refers to the state where operators, due to being disengaged from the system and not being aware of system functionalities, gets a false sense of normalcy, thereby causing complacency to creep in. In fact, this factor has many aspects which are quite similar to that of ‘out of the loop syndrome’ which has been discussed in section 5.1.3. Hence, automation induced complacency is not discussed in this section. In this section we shall discuss ‘automation induced error’ which refers to errors caused by the system, i.e. the system which in fact is meant to ensure safe operations. Automation induced error is actually responsible for some of the aircraft accidents in past, where many lives were lost. However, it is argued that a large percentage of automation induced accidents are due to system engineering (Besco & Funk, 1999). Another reason for ‘automation induced error’ is the rapid introduction of technology without full appraisal of relevant human factors and accidents caused by these factors are attributed to ‘clumsy automation’ i.e. automation where there is poor coordination between human and machines, and by ‘automation surprise’ i.e. when the system behaves in a manner not expected by the operator. Under these conditions it becomes very difficult for the operator to know the actual state of the system (Man et al., 2019). One of the main issues is that while developing new technology, user needs and limits are not fully incorporated, and it is expected that operators would adapt to the system. These technology-driven designs are so complex at times, that they become challenging for operators using them and often cause accidents due to human factors. To overcome these challenges opting for Human Centred Designs (HCD), or ‘matching autonomy to human performance’ would enable better human machine interaction, thereby reducing chances of human error including automation induced error.

The following is recommended to control ‘automation induced errors’ in autonomous ship operations.

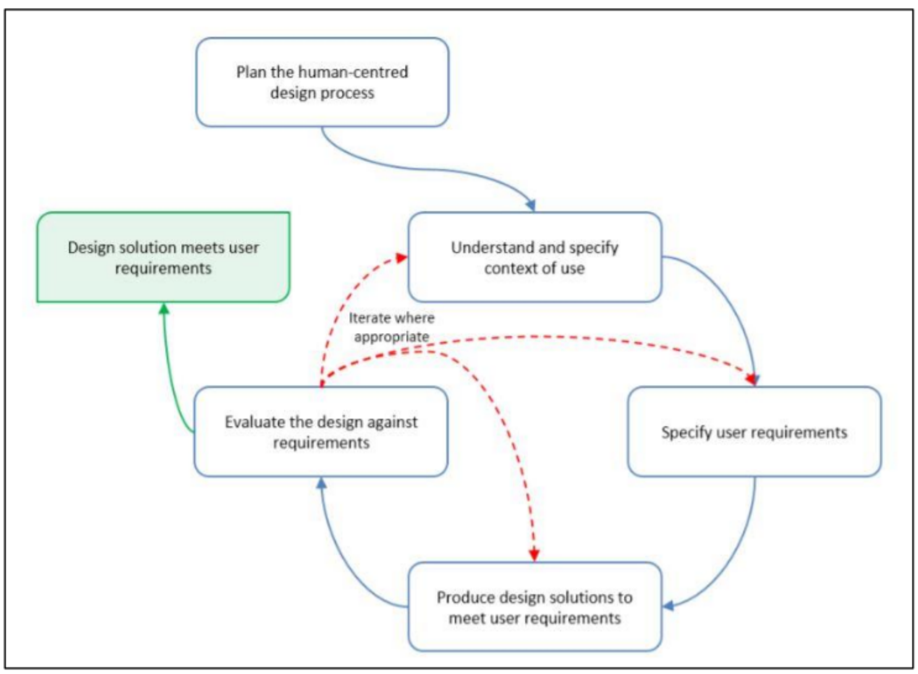
5.1.4.1 Human centred design

HCD is a method where the user is the centre for the development of the system or product, instead of technology-driven designs where it is expected that operators must adapt to the technological requirements. The HCD approach is recommended for autonomous ships as it focuses on the iterative process where the end user is part of all the development stages, i.e. conception, design, planning and implementation. Studies have shown that the HCD approach results in enhanced efficiency and reduction in human error (Kristoffersen, 2020; Rothblum, 2000). Acknowledging the benefits of

HCD approach, in 2015, the IMO adopted HCD guidelines for development of e-navigation systems (Kristoffersen, 2020). The International Organisation for Standardisation (ISO) has developed a standard - ISO 9241-210:2019 - which gives the requirements for an HCD approach for computer based interactive systems. The design stages of the HCD approach are shown in Figure 5. Further, a study conducted by World Maritime University (WMU) in 2015, introduces Crew Centred Designs (CCD), which expands on the HCD approach by incorporating designs which are fit not only for single user but are suitable for the crew collectively. Hence, CCD approach may be adopted for equipment or tasks on board ships where more than one crew member is required to perform as a team (Kataria et al., 2015).

Figure 5

HCD cycle for interactive systems (Source: ISO 9241-210:2019)



5.1.4.2 Matching automation to human performance characteristics

In this approach, one of the important considerations for the system design is how human performance characteristics interact with automation and autonomy i.e. how the operator responds to system imperfections and is able to recognise and recover from system failures. Presently the level of automation depends on unidirectional factors like reliability of available technology and economic considerations. However, the level of automation or autonomy should depend upon the amount of information processing required at each stage, considering human factors like situational awareness, workload, and complacency (Parasuraman et al., 2000). To start with, this approach recommends the use of lower levels of autonomy where automation plays the role of critiquing the operator's action by providing alternate options or choices that complement the operator's actions, thereby lowering the chances of automation induced errors. Though much of the benefit of this system arises from the lower degree of automation, however as the technology and human-machine interaction matures, the level of automation may be increased, keeping adequate human interaction for situations where cost of failure is high (Lee & Seppelt, 2012).

5.1.5 Personal factors – Training and knowledge

This research did not show 'training and knowledge' as a human factor that has significant effects on autonomous ship operations. However, as seen from the research results of human factors affecting RPA operations, it remains an important human factor consideration. The reason for it not being reflected as a significant factor for the autonomous ships in the literature may be the fact that autonomous ships are still at the design stage. However, it would be prudent to identify measures to control this factor prior to the rollout of autonomous ships. Hence, based on the training and competency regime in place for the remote operators of the RPAs, an interrogation of the way forward for training and certification for remote operators of the autonomous ships is recommended. While ascertaining training and certification regime was not germane to the core of this research, an attempt was made subjectively to suggest a probable training and certification regime for MASS operators, which is attached as Appendix A.

5.1.6 Physiological factors – Stress and fatigue

The literature reviewed did not indicate stress and fatigue as a contributing human factors consideration affecting autonomous ship operations. This may be because autonomous ships are still in the design phase. However, analysis of RPAs operations clearly shows that stress and fatigue are important factors affecting operations. Further analysis indicated that the operational demands of autonomous ships and RPAs are not similar, as flight time is mostly in hours, while autonomous ship voyages may last days or even weeks. However, while there are notable differences there will be similarities as well especially regarding shift-work and the environment of shore control centres.

Long working hours is one of the main factors which induce occupational stress and fatigue. There is considerable variation amongst countries regarding practices pertaining to working hours. Even in developed countries working hours vary and weekly working hours are seen to range from 44.7 hours for European Nations, 50 hours for Japan, 41 hours for United States. Further, it is noted that amongst the developed nations United Kingdom has highest percentage of workers who work over 50 hours a week. Experiments conducted showed that reducing weekly working hours from 53 hours to 48 hours did not result in decrease in productivity and reducing daily working hours from 9 hours to 8 hours led to about 3% increase in productivity. Most of the studies indicate that adverse health effects occur when working beyond 50 hours a week (Spurgeon et al., 1997). The terms “extended or long hours of work” refer to working more than 48 hours a week (Harrington, 2001).

From the present information, it is perceived that autonomous ship operations would involve shift-work and remote operators may be handling multiple ships at any given time. It may be noted that the stress and fatigue are significant human factors effecting the maritime industry and various measure have already been adopted to minimise both stress and fatigue at sea. The experience of maritime industry may also be used to formulate strategies for handling stress and fatigue during autonomous ship operations. The following is recommended for minimising stress and fatigue during autonomous ship operations.

5.1.6.1 Managing work hours and shift work

As found in this research, the number of hours worked and shift-work schedule, plays an important role in inducing stress and fatigue in workers and are some of the main causes of stress-related chronic health issues in the workers. Hence, to ensure optimum productivity and no adverse effect upon health, the working hours should be restricted to a maximum of 48 hours per week. Furthermore, it is recommended to follow eight-hour shift over twelve-hours shift (Harrington, 2001). The night shift work should be spread across a maximum number of operators and the number of continuous night shifts should be restricted to a maximum of three, so that the circadian rhythm is not substantially upset and there is no accumulation of fatigue. Shifts should be rotational types and should follow the clockwise rotation i.e. morning – afternoon – night, as it follows the natural tendency of the circadian rhythm. At least thirty-minute meal breaks and fifteen-minute tea breaks every two hours should be provided. At least two consecutive off days should be planned between the shift cycles and a day off should be given after completion of continuous night shifts (Costa & Folkard, 2010).

5.1.6.2 Adequate manning

Understaffing is also one of the key reasons for stress and fatigue in workers and needs to be dealt with by the administration and the organisation. Depending on various factors such as voyage length, number of port calls, type of autonomy, type of vessel, etc. each operator should not be allowed to handle more than a certain number of ships. In addition, a senior operator should be assigned, who should be supervising not more than four operators. This would ensure that workload is well distributed amongst operators and there is availability of backup if and when needed. This is in line with procedures adopted by RPAs in the aviation industry.

5.1.6.3 Adequate organisation culture, environment, and training

The work environment should be designed to minimise fatigue and promote alertness. Temperature, humidity, noise levels and lighting play a key role towards achieving this. At the SCC, optimum temperature and humidity level should be maintained. Studies show that the average continuous 24-hour period sound levels in hospitals is around 50 to 65 decibels (Busch-Vishniac et al., 2005; Park et al., 2014). The SCC should be well insulated from external noise and in any case should not be more than 65 decibels which is the maximum level observed in the hospitals. Studies show that exposure to blue-enriched white light enhances alertness and performance, and reduces fatigue (Viola et al., 2008). Hence, it is recommended that blue-enriched white light with adjustable intensity should be used at SCC. The organisation culture should be open and transparent, promoting positivity and there should be no undue work pressure from the organisation or line manager or colleagues. The organisation should provide 'fatigue risk management training' to its employees, where they should be taught how to recognise fatigue and the factors that induce fatigue as well as the measures to be adopted to minimise fatigue. Thereafter, it is the responsibility of the employees to ensure that these measures are adopted by them to mitigate occupational fatigue.

5.2 Conclusion

With regards to autonomous ship operations, this research studied existing literature to explore the human factors that would pose significant effects on autonomous ship operations. The study was conducted through a comparative analysis of human factors affecting autonomous operations in the aviation industry and those that would have significant effects on autonomous ship operations.

The research showed that some human factors like 'situational awareness', 'data overload', and 'out of the loop syndrome' have already been identified as human factors affecting autonomous ship operations. However, this research identified some of the key mitigating measures for controlling these factors based on the aviation industry’s successful experiences. It was interesting to note that the human factor ‘workload’ though shows up as a significant factor for the aviation industry, but does not seem to have the same significance for the autonomous ship operations and the reason for this is the difference in the operational requirements of the two industries.

‘Automation induced error’ human factor may be considered as an emerging factor for autonomous ship operations. While this plays a vital role in the aviation industry, it does not show up as a significant factor affecting autonomous ship operations. In fact, the maritime industry is still looking at ‘automation induced complacency’ which is quite different from ‘automation induced error’, being closer to the human factor related to ‘out of the loop syndrome’. Hence, this study considers ‘*automation induced error’ as an emergent human factor* issue for autonomous ship operation. Furthermore, due to the current development stage of the autonomous ships, the maritime industry is presently focusing more on equipment-related human factors. However, based on the comparative analysis with the aviation industry, this study has analysed human factors such as ‘stress and fatigue’ and has recommended mitigating measures for controlling same.

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Appendices

Appendix A – Suggested training and certification regime for MASS operators

During this research and also through related and emergent issue of training and certification of MASS operators, even though this issue was not the core of the work, a subjective brainstorming exercise was carried out, the outcome of which is follows:

Currently, seafarer education and training is primarily governed by the International Convention on Standards of Training, Certification and Watchkeeping (STCW), 1978, as amended. Autonomous ships, depending upon their level of autonomy, would be fitted with different equipment having different levels of automation and technology, and would therefore need to be operated by personnel having the required knowledge and skills presently which are not covered by the STCW Convention and Code (Deling et al., 2020). Hence, a new training and competency regime needs to be established to ensure that there are enough competent and skilled personnel available for operating autonomous ships. The following indicate probable training requirements for different levels of autonomy of the autonomous ships.

Degree 1 autonomous ships would be equipped with decision support systems and automated systems to aid onboard seafarers, who would have control of the ship. Some of the systems installed would be capable of unsupervised operations when and if required. Hence, these ships would be fitted with modern automatic control systems, having a fair amount of automation and technology. Many of the existing ships do fall in this category. All seafarers should receive basic training in automation and autonomy, cyber security, and information technology.

Degree 2 autonomous ships are remotely operated with a limited number of seafarers on board. These ships would be fitted with a higher level of automation and a few seafarers on board to take control if required. The role of seafarers on board these ships would be quite different from the role of seafarers on board conventional ships. Since these ships are operated remotely, these would be fitted with equipment having high levels of automation and technology. Both onboard seafarers and remote operators would need training to develop skills and attain knowledge, so that they are able to proficiently perform their functions onboard and from ashore.

Degree 3 autonomous ships are remotely operated ships without any seafarers on board. These ships would be equipped with systems which would allow remote operators total control of the ship. Since there are no seafarers on board, it is expected that levels of automation and redundancy would be extremely high. Given that the remote operator would not have any assistance of onboard seafarers the training imparted should instil greater knowledge and understanding of the automation and technology used, including redundancies available onboard.

Degree 4 autonomous ships are fully autonomous ships i.e. these ships are equipped with systems that enable them to automatically accomplish almost all shipboard tasks and decision making, including in navigational situations. In this case the remote operator mainly performs supervisory function. However, he/she must be capable and competent to take over controls immediately, whenever necessary. Remote operators for these ships need training so that they become fully competent and skilled to operate the fully autonomous ships. It is critical that the operator fully understands the system and is always in synchrony with system functionalities and is able to takeover control when required (Deling et al., 2020).

The recommendation below provides the structure and framework for the certification and training process for MASS operators and does not go in details or content of the suggested training.

A1 – Institutionalising a mandatory certification and training regime

The following mandatory certification and training is recommended to ensure all personnel operating autonomous ships have the necessary knowledge and skills. It is proposed that three levels of responsibilities are incorporated for certification of MASS operators i.e basic level, intermediate level, and advanced level. This process is actually a transition process for existing seafarers. Once this process matures, the same philosophy could be used to form a pathway i.e. education and training required for the new ship operators. The transition of existing seafarers would be a continuous and long process as conventional ships would continue to exist and operate alongside autonomous ships for a considerable period. Three levels of Certificate of Competency (COC) may be introduced with following criteria.

A1.1 – MASS COC – Basic Level

Mandatory for: All seafarers on board degree 1 and degree 2 autonomous ships.

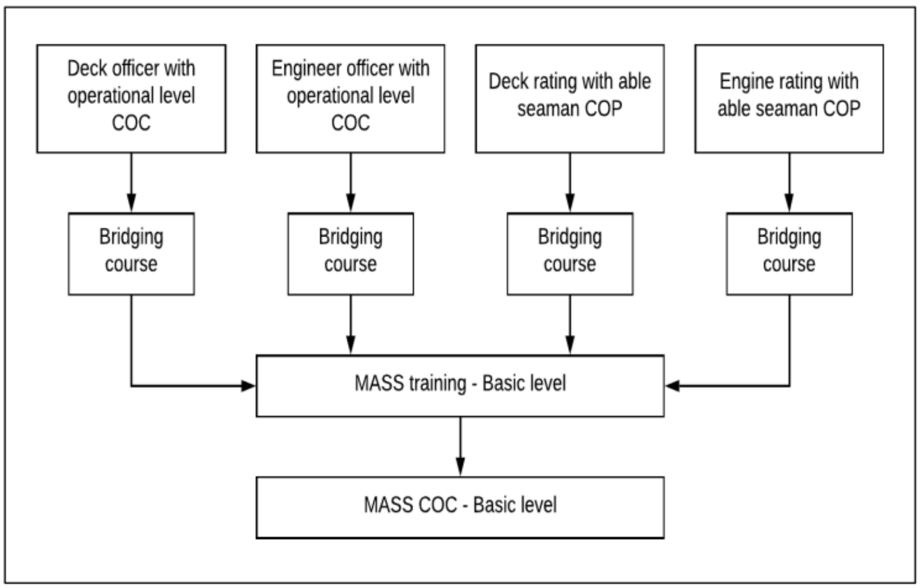
Eligibility: Existing four streams, i.e. deck officer with operational level certificate of competency (COC), engineer officer with operational level COC, deck rating with able seaman COP and engine rating with able seaman COP.

Training required: ‘MASS training – Basic level’ and ‘bridging course’ for each stream. Basic level MASS training course would enable candidates to would develop skills and gain knowledge required for onboard operations on degree 1 and degree 2 autonomous ships. Bridging course for each stream would cover competency gaps identified between their existing certification and those required for the Basic level MASS COC.

COC Issuance: Successful completion of training by eligible candidates would lead to issuance of MASS COC – Basic level. Figure below illustrates in detail.

COC Revalidation: Every 5 years. After attending revalidation course and completing minimum required service period.

Process flow for MASS COC – Basic Level



A1.2 – MASS COC – Intermediate Level:

Mandatory for: All remote operators of degree 2 and degree 3 autonomous ships.

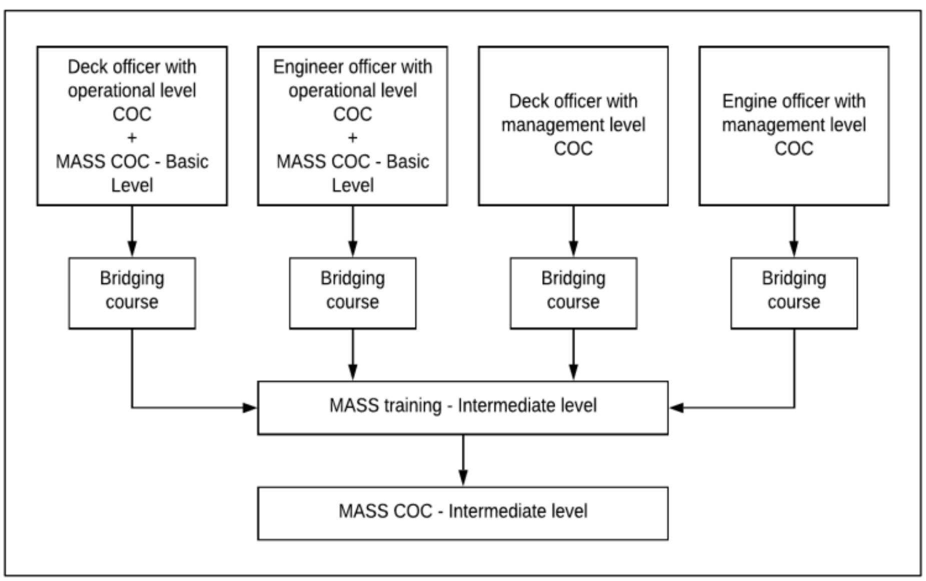
Eligibility: Existing operational level deck and engine officers holding 'MASS COC – Basic Level' and existing management level deck and engine officers.

Training required: 'MASS training – Intermediate level' and 'bridging course' for each stream. Intermediate level MASS training course would enable candidates to develop skills and gain knowledge required for remote operations of degree 2 and degree 3 autonomous ships. A bridging course for each stream would cover competency gaps identified between their existing certification and those required for the Intermediate level MASS COC.

COC Issuance: Successful completion of training by eligible candidates would lead to issuance of MASS COC – Intermediate Level. Figure below illustrates the details.

COC Revalidation: Every 5 years. After attending revalidation course and completing minimum required service period.

Process flow for MASS COC – Intermediate Level



A1.3 – MASS COC – Advanced Level:

Mandatory for: All remote operators of fully autonomous ships i.e. degree 4 autonomous ships.

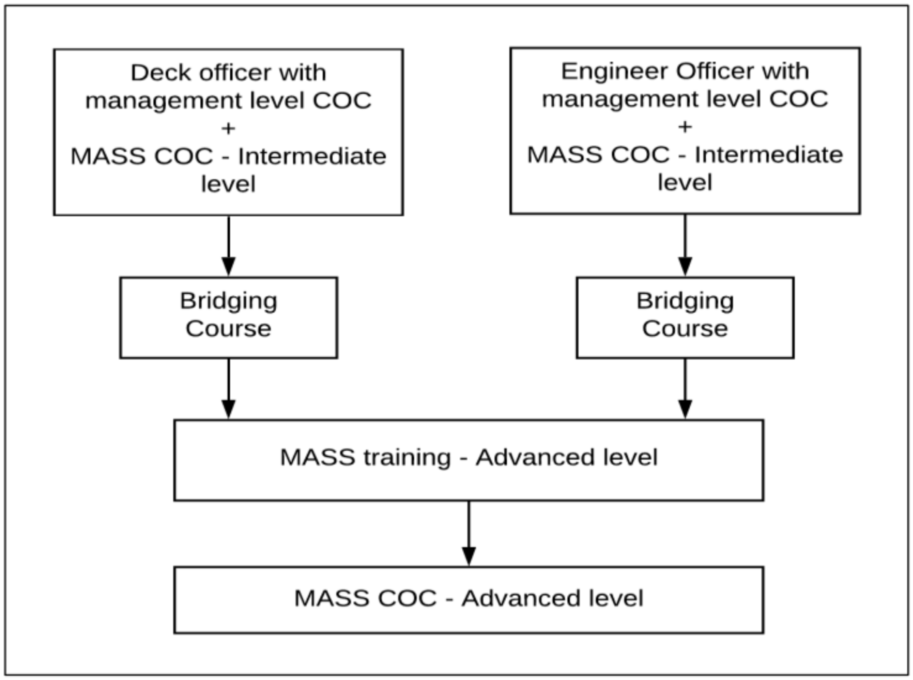
Eligibility: Management level deck and engine officers holding Intermediate level MASS COC.

Training required: 'MASS training – Advanced level' and 'bridging course' for each stream. Advanced level MASS training course would be the highest-level MASS training where candidates would develop skills and gain knowledge required for remote operation of fully autonomous ships i.e. degree 4 autonomous ships. A bridging course for each stream would cover competency gaps identified between their existing certification and those required for Advanced level MASS COC.

COC Issuance: Successful completion of training by eligible candidates would lead to issuance of MASS COC – Advanced level. Figure below illustrates this in greater detail.

COC Revalidation: Every 5 years. After attending revalidation course and completing minimum required service period.

Process flow for MASS COC – Advanced Level



Appendix B – Bibliographic list

B1 – For SLR of human factors affecting the autonomous ship operations

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B2 – For SLR of human factors affecting remotely piloted aircrafts

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